ANTIBARYON PHOTOPRODUCTION USING CLAS AT JEFFERSON LAB

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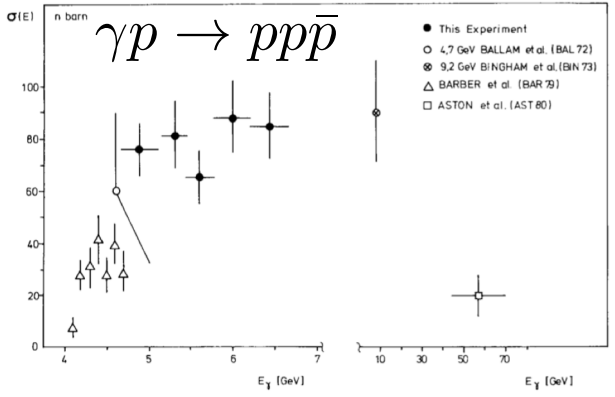
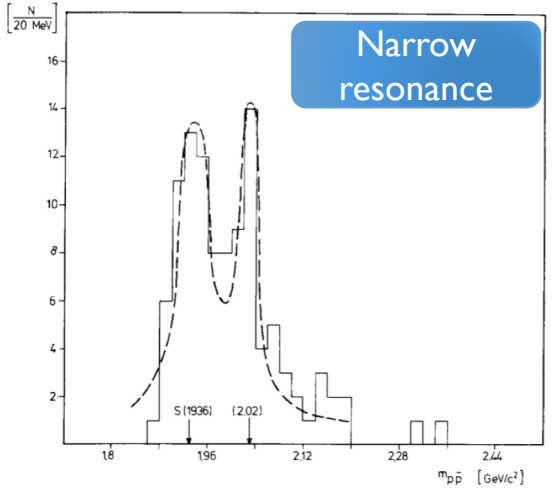
Overview

- History
- Experiment Overview
- Search for Narrow Resonances
- Monte Carlo Generator Details
- Cross Section Measurements
- Antineutron Reaction Cross Section
- Summary

History of Antibaryon Photoproduction

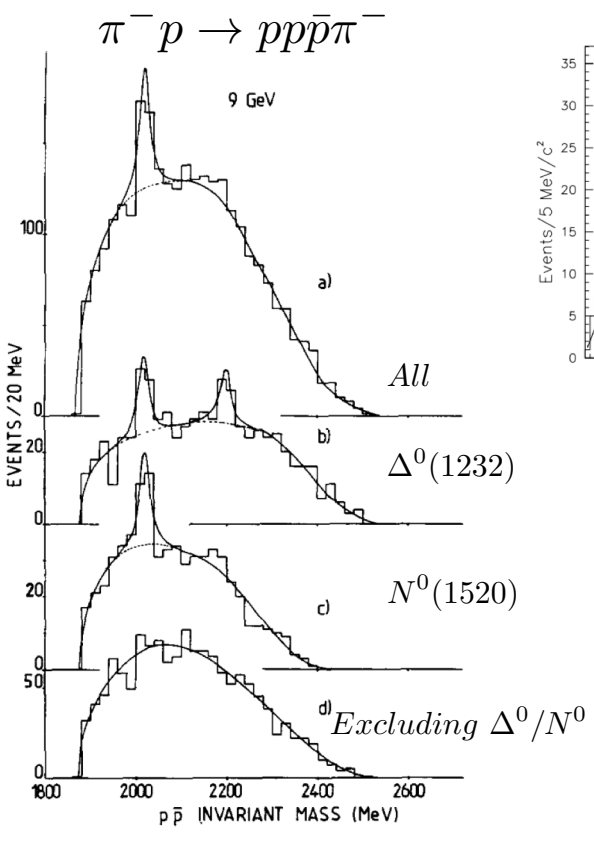
- Antibaryon photoproduction has been studied since the advent of nuclear physics
- Primarily motivated by the potential for bound proton antiproton bound states
- Evidence reported for narrow resonances in earlier experiments that later experiments do not show
- Total cross sections have been measured
- Photoproduction mechanism is unknown, differential cross sections were never measured



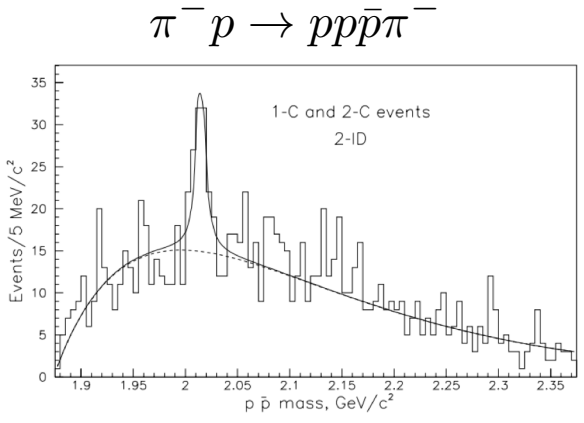


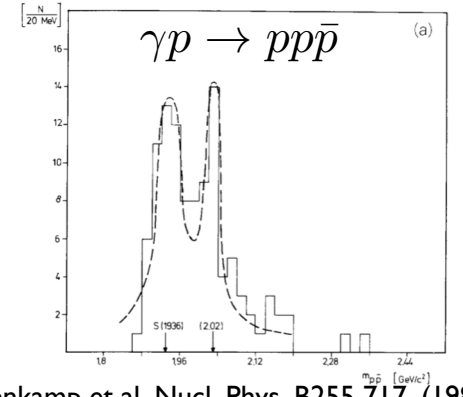
Narrow Resonance History

- Narrow resonances have been long been sought after as potential baryonium states
- Early photoproduction experiments from DESY and LAMP2 claim to see evidence for narrow resonances at 2.02 and 2.2 GeV
- Narrow resonances observed in pion production with the latest results still showing evidence for a narrow resonance



P. Benkheiri et al., Phys. Lett. B 68, 483 (1977)



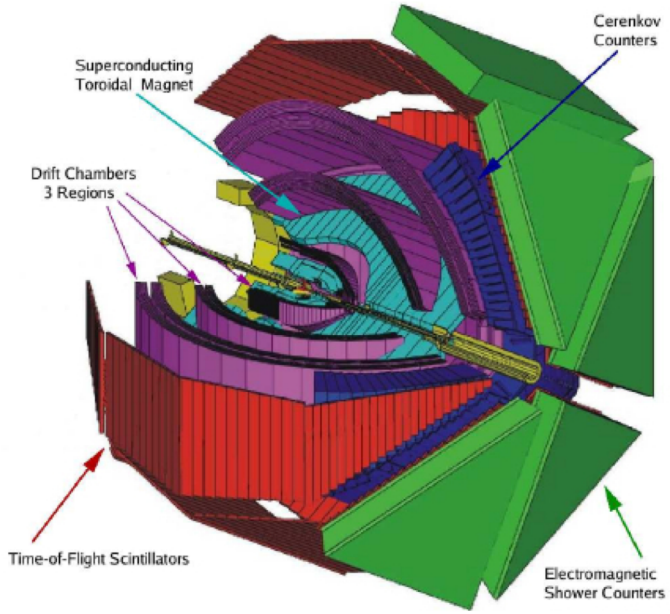


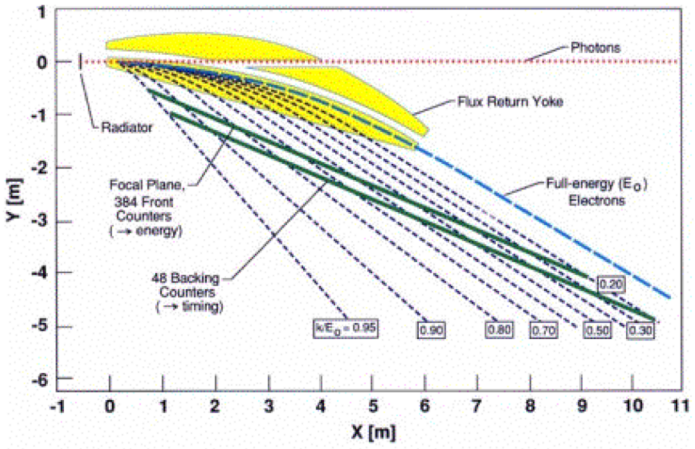
Bodenkamp et al, Nucl. Phys. B255 717. (1985)

Experiment Overview

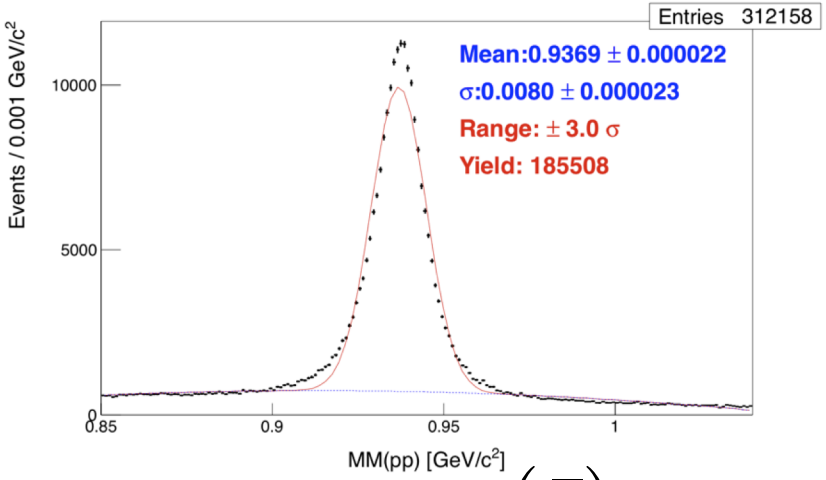
- g12 experiment
  - LH_2 target, ran in 2008
    - Target was -90 cm from center of CLAS
  - Photoproduction: 1.1-5.45 GeV
    - Circularly polarized
  - Total integrated luminosity: 68 pb^{-1}
  - $7 \cdot 10^7$ tagged photons/s
  - Highest statistics photoproduction experiment to date in this energy range

40 cm LH_2 target

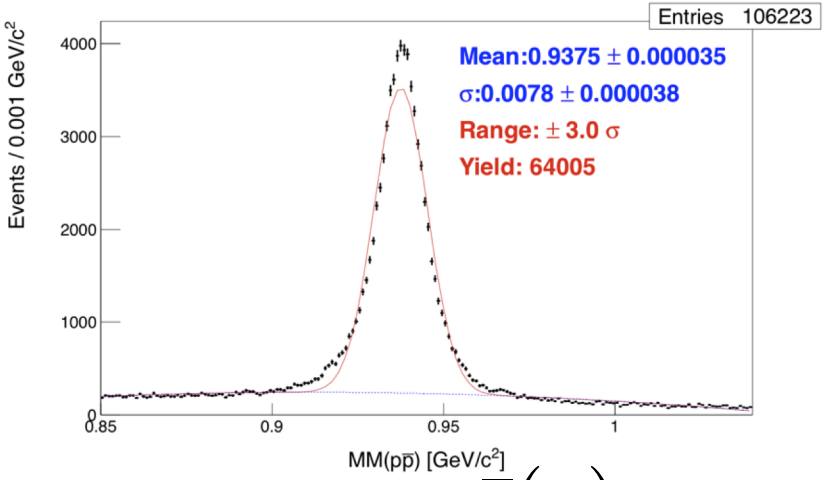




Experimental Results: Features of the Data



$$\gamma p \rightarrow pp(\bar{p})$$

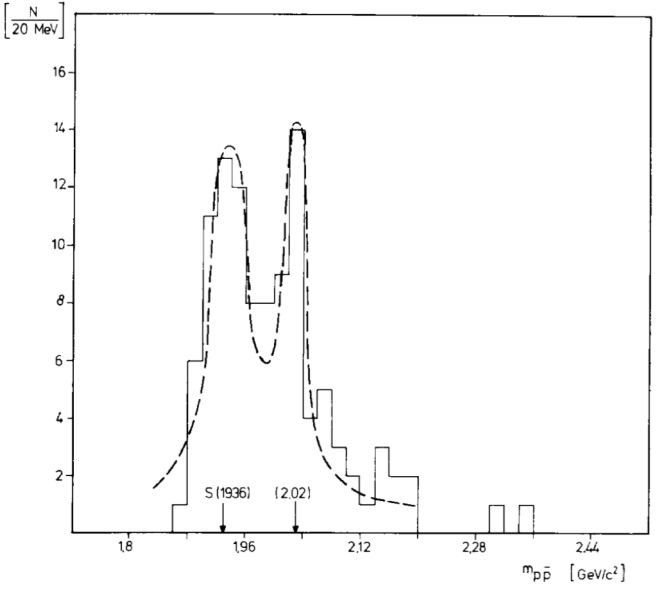


$$\gamma p \rightarrow p\bar{p}(p)$$

- Unprecedented statistics in proton antiproton photoproduction
- E_γ from reaction threshold (3.9 GeV) to 5.45 GeV
- $2.5*10^5$ events combined

Experimental Results: Narrow Resonances?

$$\gamma p \rightarrow pp(\bar{p})$$



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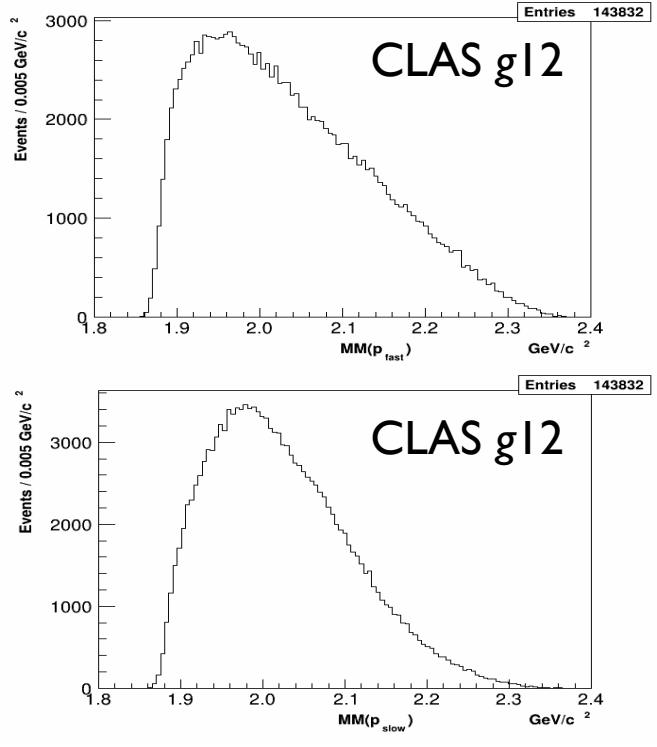
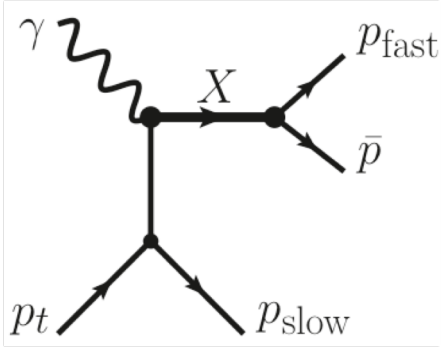


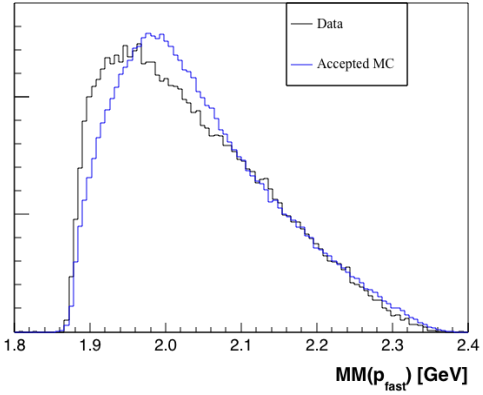
- Narrow resonances have been observed in the past
- No clear evidence for narrow resonances in current analysis

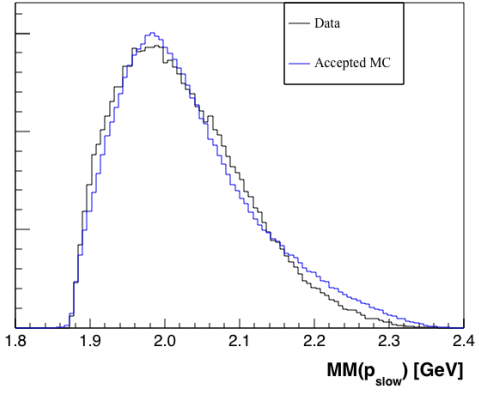
Note: E_γ from 3.9-5.5 GeV

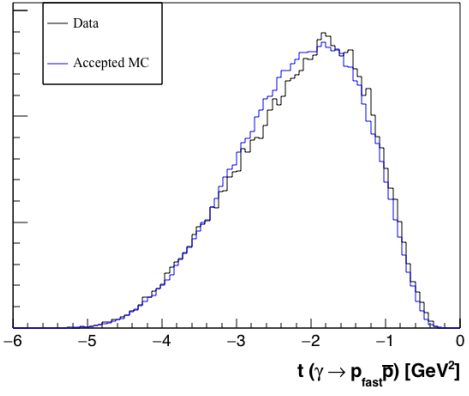
Initial Monte Carlo Model

- The first model that was used is a diffractive model tuned to be as close to data as possible
  - Similar to accuracy of previous measurements
- Not an accurate model, differential cross sections calculated using this model are used as an input to a custom weighting program



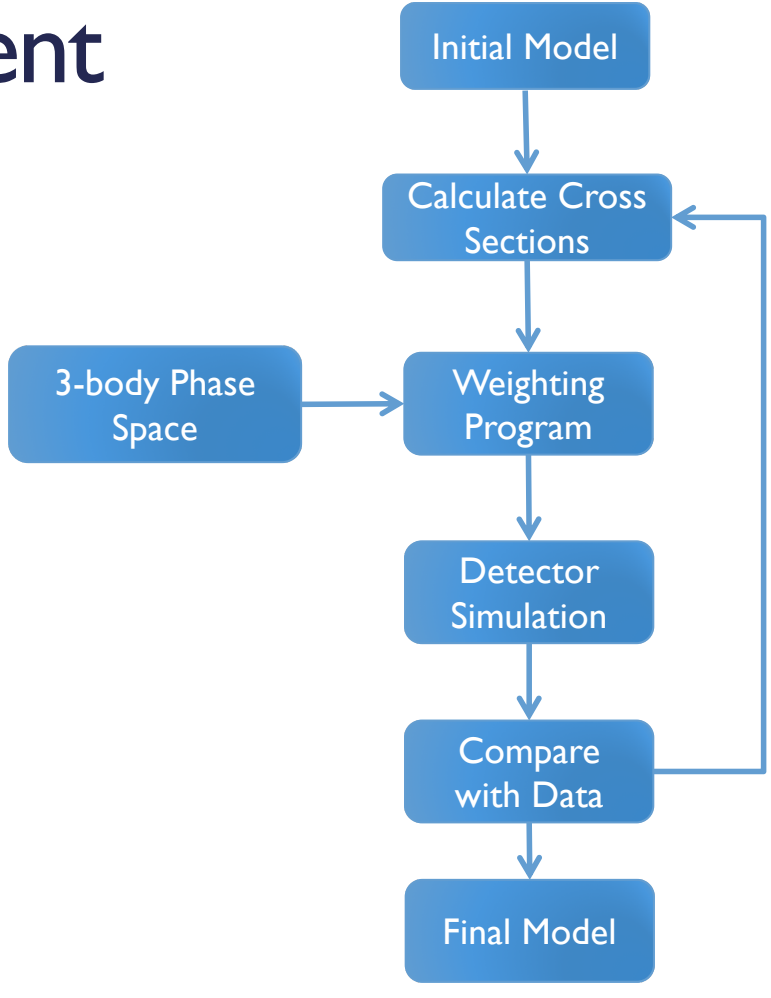






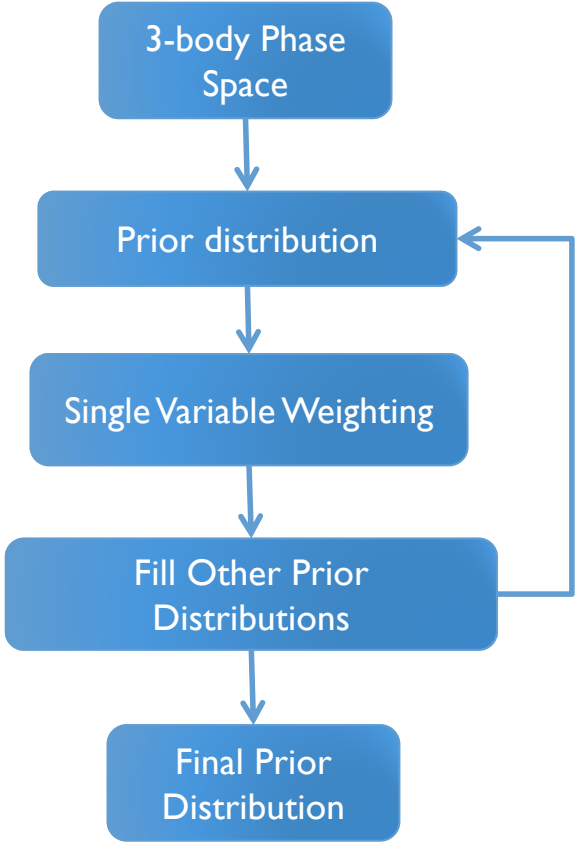
Generator Development

- Detector efficiency calculations are model dependent therefore it is crucial that the model matches the data well
- Other generators were unsuccessful at matching with the data
- The solution was to create a generator using cross sections as an input
- The generator is based on rejection sampling and since the input is calculated using the Monte Carlo model it is iterated until they match



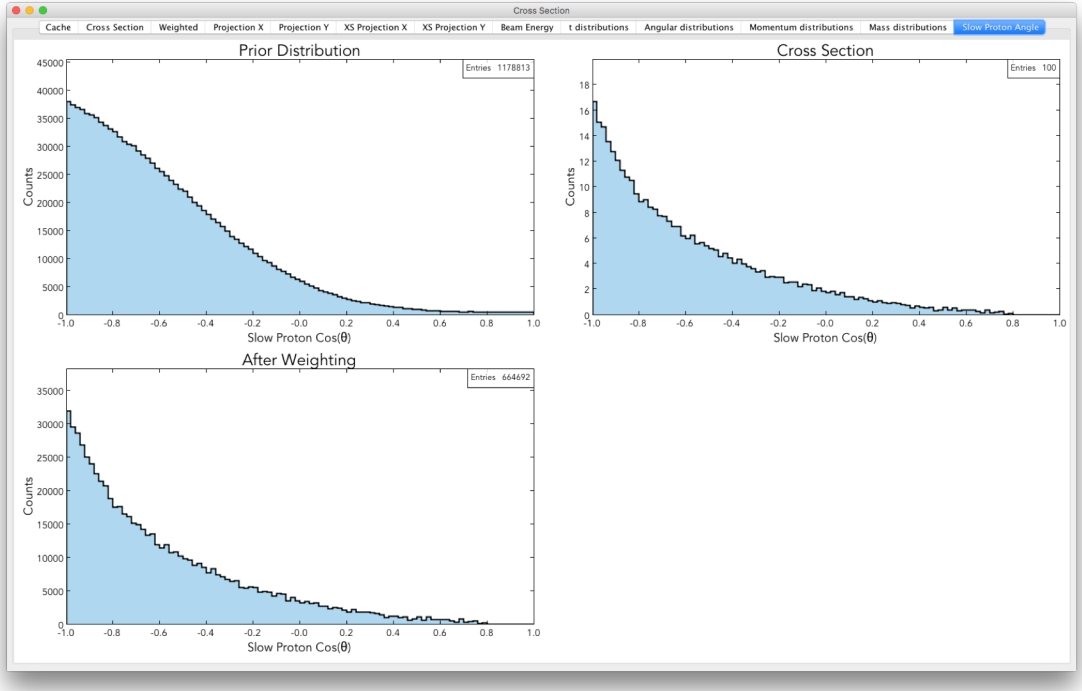
Prior distributions

- Weighting the events properly requires taking into account the prior distribution
- Ideally the events would be weighted from a 6 dimensional cross section however the statistics were limited
- Each distribution must take into account the effect of the other weighting distributions on the prior distribution
- This is repeated until the generator model matches the input cross sections



Weighting Program Specifications

- The weighting program is written in Java using libraries from the CLAS12 software framework and the GROOT graphics package
- Graphical features: All weighting distributions are shown for ease of debugging
- Includes batch mode for running on the farm and command line arguments for changing parameters on the fly



Weighting Distributions

- Four distributions were used in the weighting process starting with the two dimensional cross section
- This was not enough to constrain the model so one dimensional flux normalized profiles were added one by one to match the accepted Monte Carlo with the data
- The photon energy dependent cross section provided an accurate beam energy profile

Cross section data:

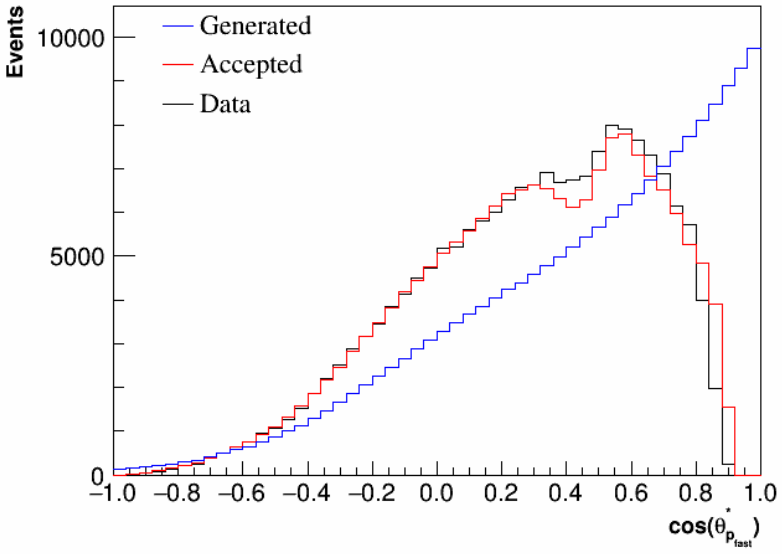
$$\frac{d^2\sigma}{dM(pp)d\cos(\theta^*_{\bar{p}})}$$

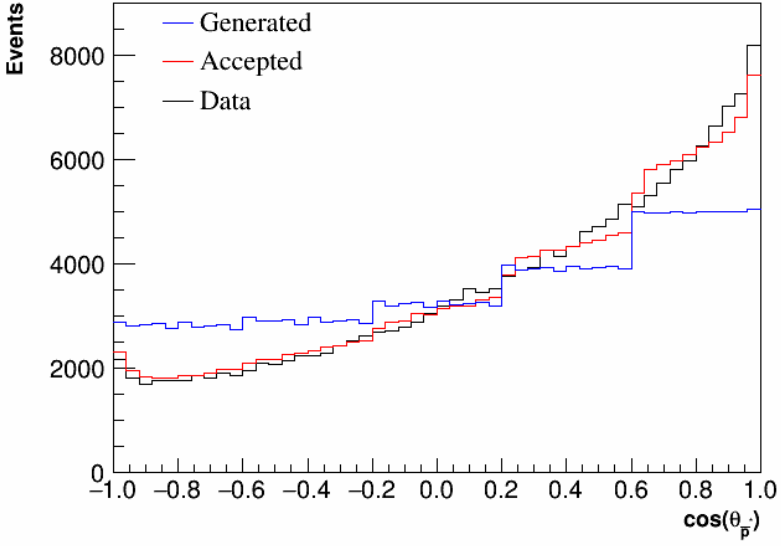
One-dimensional Profiles:

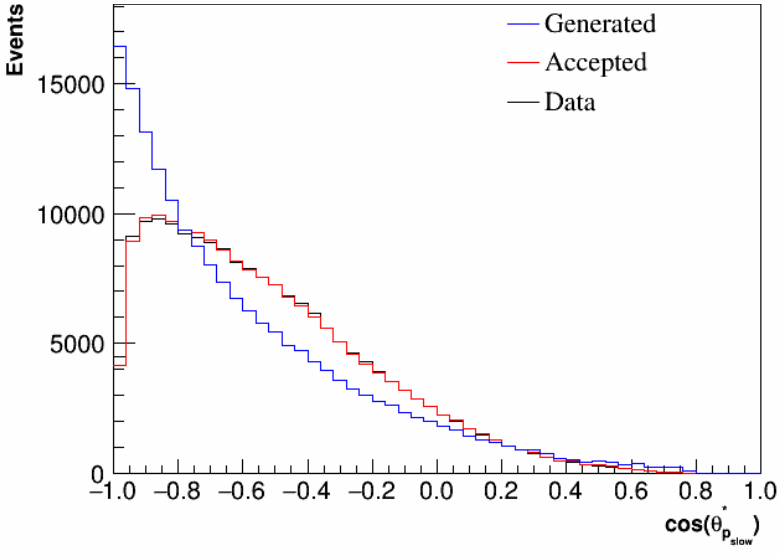
$$t_{baryon} \quad \cos(\theta^*_{p_{slow}}) \quad M(p_{fast}\bar{p})$$

MC Comparison

- The final model from the new generator matches the data very well in all kinematic distributions
- Further tuning and interpolation of the cross sections could improve results further

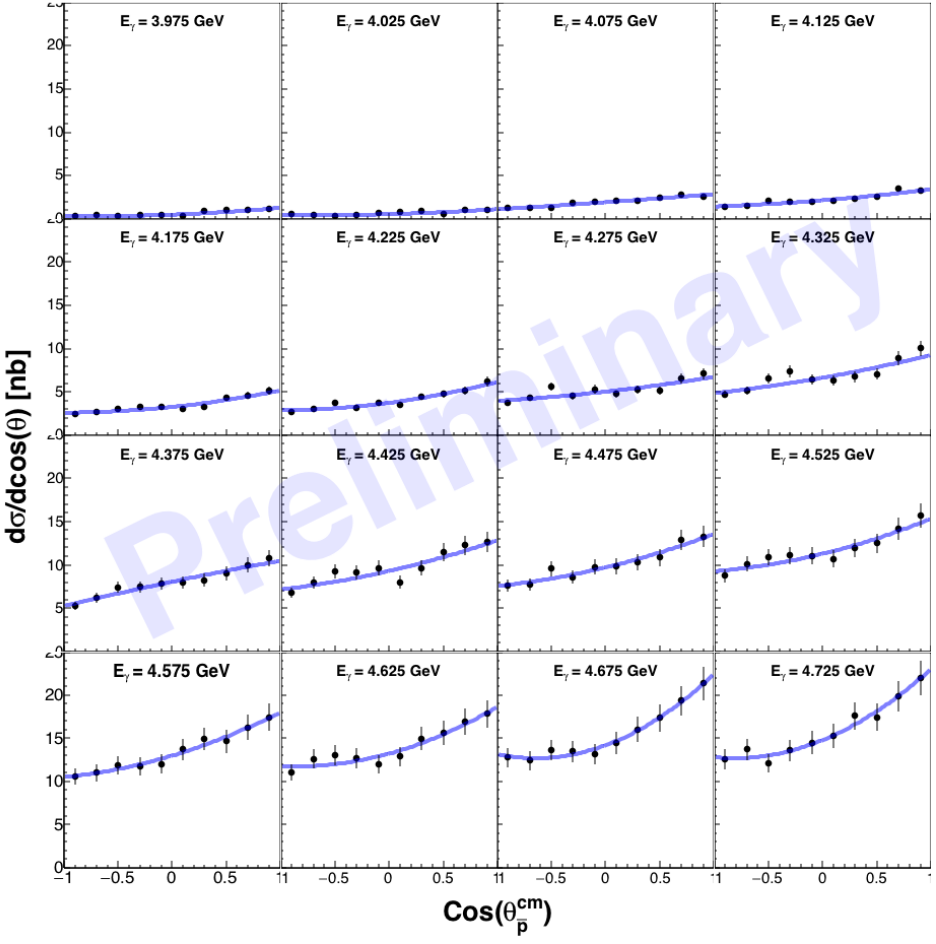






Differential Cross Section Measurement

- First (preliminary) angular differential cross section measurement shown, E_γ from 3.95-5.45 GeV
- Fits to Legendre polynomials are used to describe how the shape changes as a function of energy



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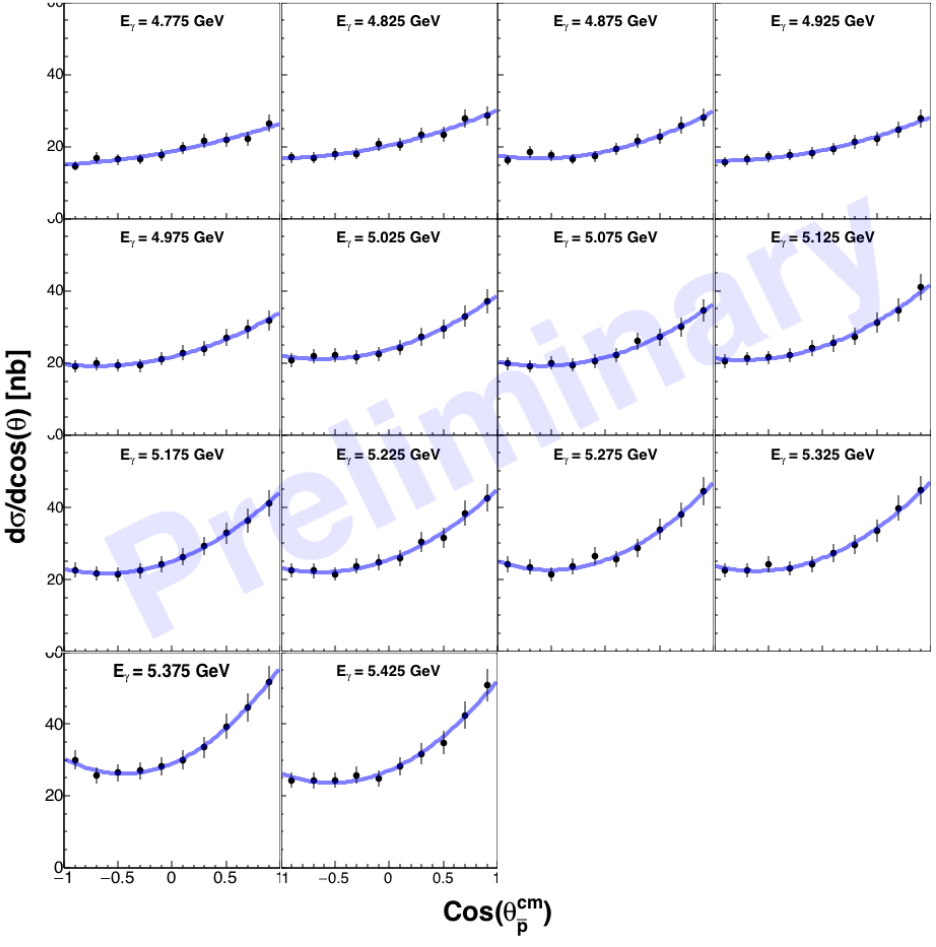
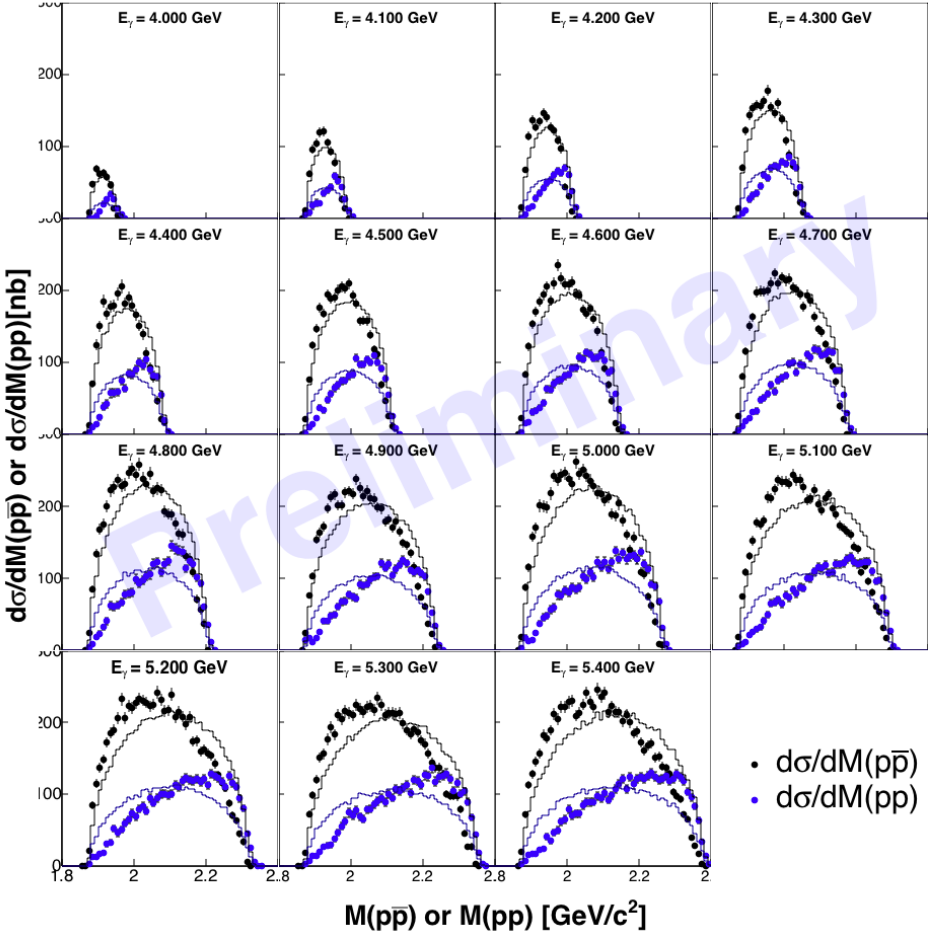


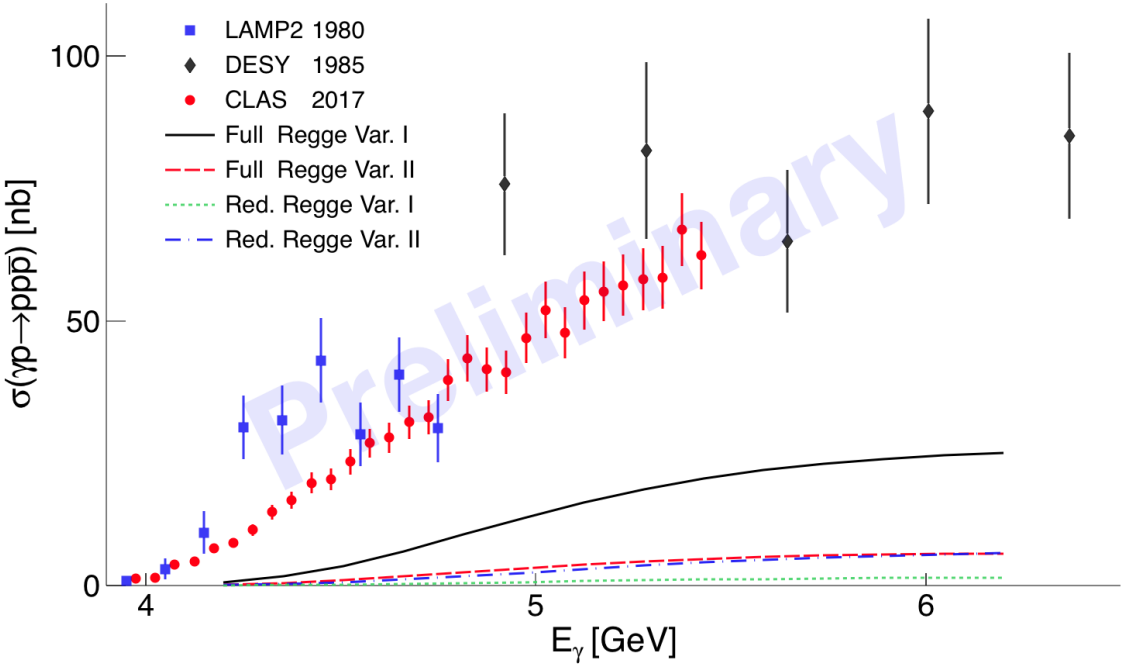
Differential Cross Section Measurement

- Differential cross section shown, E_γ from 3.95-5.45 GeV
- Double counting in the ppbar mass cross section due to the ambiguity between the protons
- 3-body phase space MC is shown as a histogram and it is clear that the production mechanism is not purely phase space
- No evidence for narrow resonances



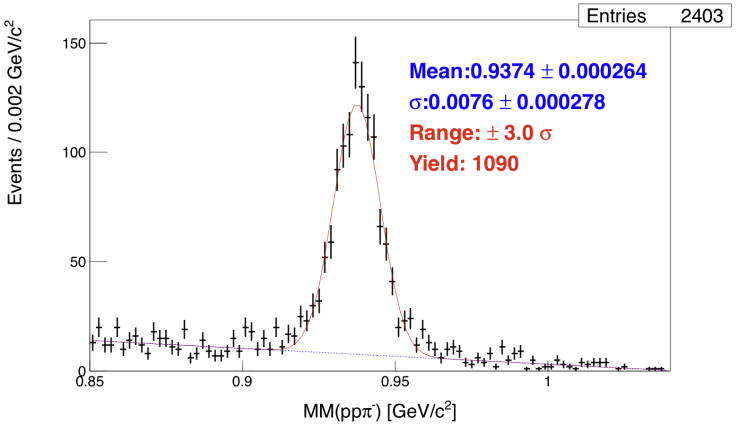
Total Cross Section

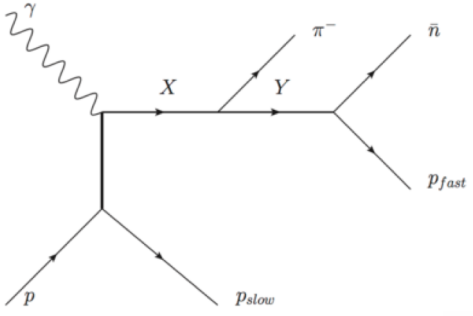
- The preliminary total cross section was measured from near threshold to 5.45 GeV
- Measurements agree with some previous measurements but are systematically lower

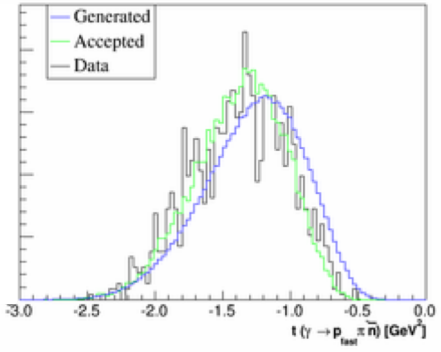


V. E. Lyubovitskij et al., *Phys. Rev.*, vol. D94, no. 3, p. 034010, 2016

Experimental Results: Antineutron Reaction

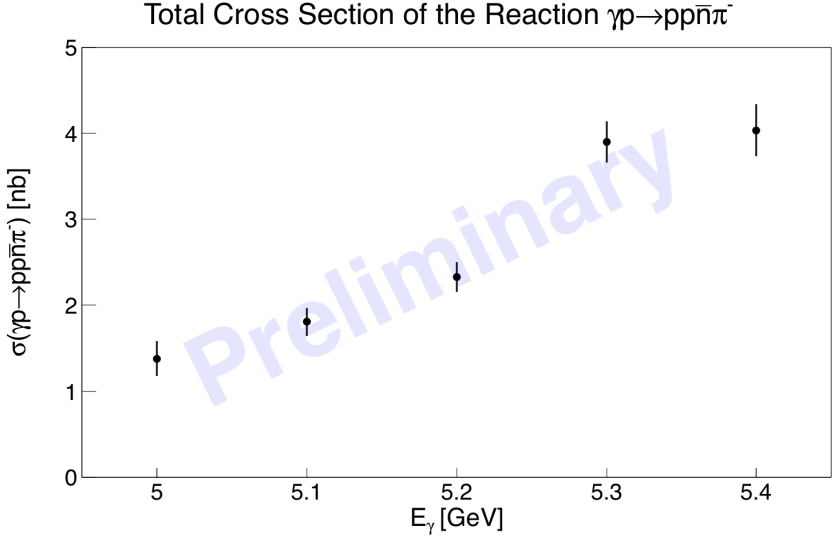






- After many iterations simulation that matches the data was found
- Momentum, angles, and t distributions match

$$\gamma p \rightarrow pp\pi^{-}(\bar{n})$$



Summary

- No clear evidence of narrow resonance production
- First time differential cross sections describing the angular and mass distributions have been measured
- Total cross section derived from the differential cross section is compared to world data and theory showing a discrepancy mainly at higher photon energies
- Accurate Monte Carlo model based on cross sections is used for these measurements that matches data very well resulting in a more believable measurement
- First time observation and cross section for an antineutron in photoproduction

Systematic Uncertainty Summary

- The individual systematic uncertainties are assumed to be uncorrelated and are added together in quadrature
- The total systematic uncertainty is 8.7% and is applied to all cross section measurements
- Scaling systematic is 5.7%

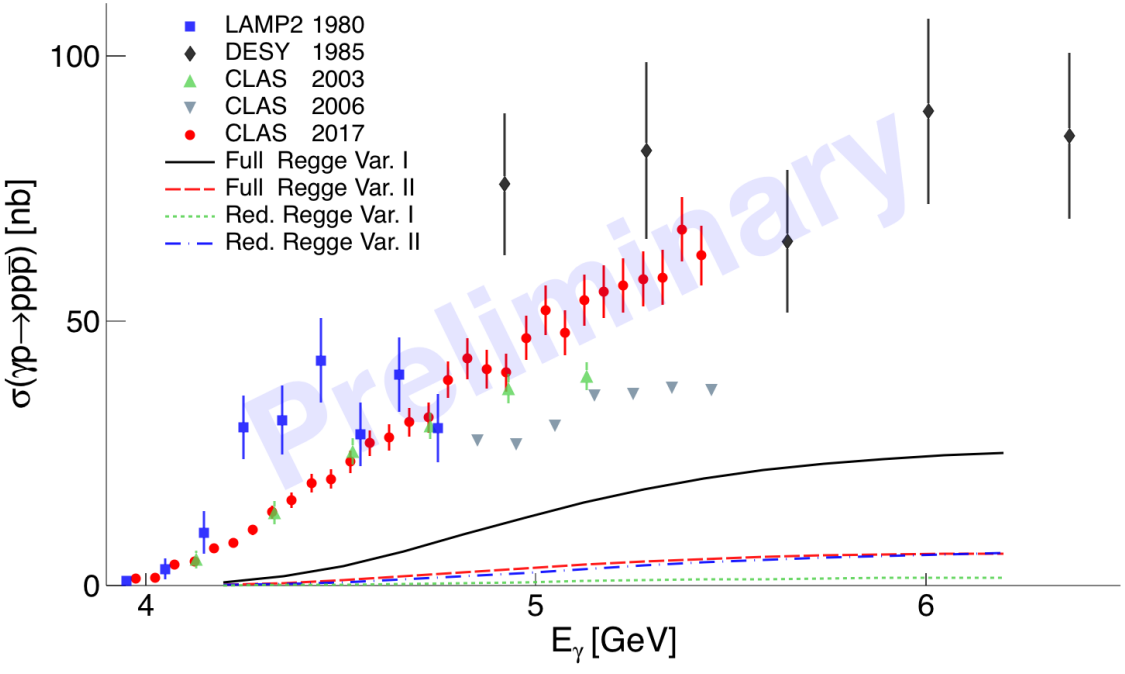
$$\sigma_{total}^{systematic} = \sqrt{\sum_{n=1}^{n_{sys}} \sigma_n^2}$$

Systematic	Relative Uncertainty
Sector	0.071
Pull Probability	0.033
Monte Carlo Model	0.022
Fiducial Cut	0.021
Track Efficiency	0.020
Target Fiducial	0.010
Total	0.087

Global Systematic	Relative Uncertainty
Photon Flux	0.057
Target Density	0.00025
Total	0.057

Total Cross Section

- The preliminary total cross section was measured from near threshold to 5.45 GeV
- The measurements are more consistent with unpublished CLAS measurements
- Measurements agree with some previous measurements but are systematically lower

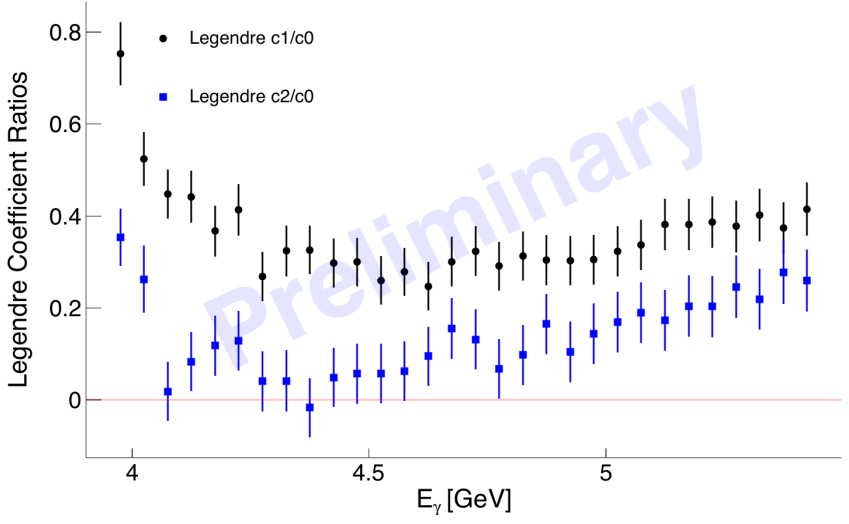


*CLAS results unpublished

V. E. Lyubovitskij et al., *Phys. Rev.*, vol. D94, no. 3, p. 034010, 2016

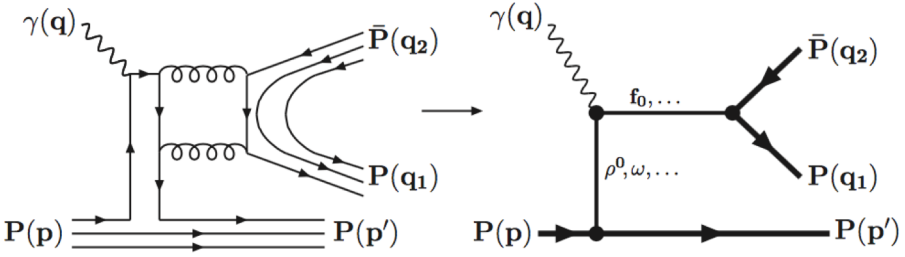
Legendre Coefficients

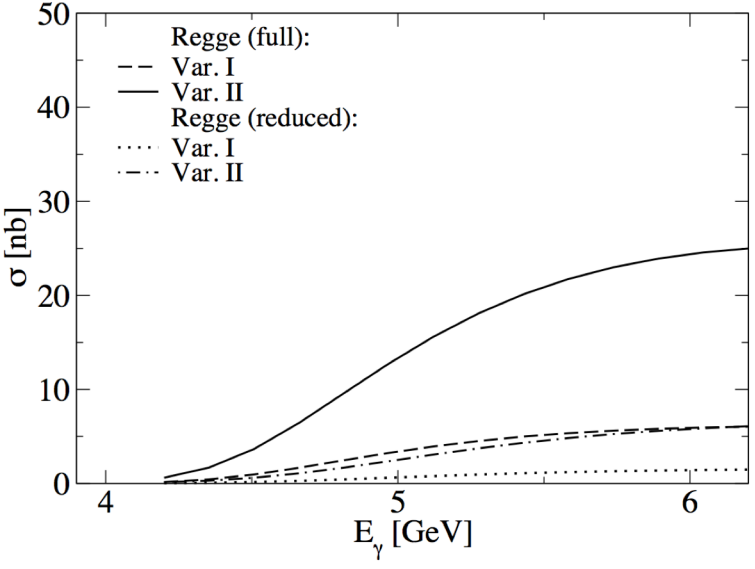
- The legendre coefficients are normalized showing the change in shape over the photon beam energy range
- There is very little change in the angular distribution other than the overall cross section increasing throughout the beam energy range



Theoretical Interpretation

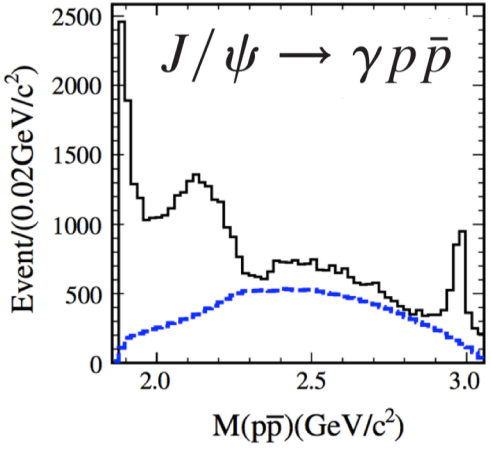
- With the advent of high statistics experiments antibaryon photoproduction has gained traction with theorists
- Predictions using an effective hadronic lagrangian incorporating two triplets of *f* mesons decaying to a proton-antiproton pair





Introduction: Meson decay

- BES III reported on near threshold mass enhancements as well as possible meson resonances above 2 GeV
- In addition, a large number of mesons are observed in proton antiproton annihilation experiments
  - Similar widths to the proton antiproton mass distribution width
  - Multiple large width mesons could be contributing
- PWA would be the only way to get a better understanding



M. Ablikim et al., Phys. Rev. Lett. 108, 112003 (2012)

Abridged Resonance Candidates (MeV)	Γ (MeV)	J^{PC}
$rho_3(1990)$	196±31	3^{--}
$f_0(2020)$	442±60	0^{++}
$f_2(2150)$	152±30	2^{++}
rho(2150)	~250-320(?)	1^{--}
$rho_3(2250)$	~220	3^{--}
$rho_5(2350)$	400±100	5^{--}
$f_6(2510)$	283±40	6^{++}

*PDG 2014